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AN OPERATIONAL DECISION MODEL EMPLOYING OPERATIONAL AND ENVIRONMENTAL FACTORS

By

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I. Introduction

The meteorologist engaged in operational forecasting is constantly striving to improve his forecast. Nevertheless, the ultimate in forecasting skill, that of predicting all future meteorological events exactly correct, is beyond him now and will remain beyond his reach in the foreseeable future. Thus, in all weather forecasts there will remain a certain degree of uncertainty. Whether this uncertainty is a hindrance to the user of the weather information or not is highly dependent upon the type of activity being planned and, consequently, in most cases is quite variable. (The thesis of this Technical Note is the demonstration of a means which will provide a measure of the degree of usefulness of meteorological information under various situations.)

The measure of the usefulness and also the effectiveness of weather information can be determined by applying well-known rules of decision theory to operational situations which are affected in some way by meteorological phenomena. This approach is not new and an excellent historical development can be found in a paper by Glahn [1]. The pioneering efforts of Glahn did not go unnoticed. Cummings [2] pointed out the value and need of such an approach. Subsequently, Huschke and Rapp [3] performed a similar analysis of a broadscale, relatively-complex, military operation. In another study Huschke [4] discussed the use of meteorological decision theory in planning requirements and specifications of weapons systems. Rapp [5] developed a simple model to stress the usefulness of weather information in activities ranging from the simplest to the most complex.

The information to be gained from analyses such as those mentioned above is invaluable to the decision-maker. In the same respect, the AWS forecaster must impart as much pertinent information as possible to his customer and, because of this, it is imperative that procedures like those discussed here are not overlooked. Indeed, an analysis of this type is an excellent vehicle to further enhance AWS-customer relationships since it requires strong interaction between AWS personnel and user agencies. Active user participation in this type of analysis is a prerequisite to obtaining meaningful results. (This requirement has been repeatedly stressed by Huschke [6] in establishing guidelines for studies of this type.)

II. The Concept.

In actuality, most, if not all, inputs to a decision are uncertain; it is the degree and quantification of this uncertainty that provides useful information to the decision-maker. Furthermore, measurements of uncertainties must be in terms that the operational decision-maker can easily understand and use.

In evaluating the effectiveness of meteorological information, the principal uncertainty must necessarily be the meteorological information itself and the task of quantifying that information belongs to the meteorological community.

With this in mind, the basic concept is to model various operational environments with weather conditions or parameters as the sole inhibiting factor (in a "simple" model). It must be assumed at the outset that decisions regarding other variables within the problem are correct. Thus, the end result is a true measure of the contribution of meteorological information.

A simple model will adequately serve to exemplify the uses and also the importance of a decision theory approach. Rather than use an actual operational situation, it was considered more feasible to contrive a simple, but somewhat realistic, situation for illustrative purposes. Even so, the meteorological data used in this model were obtained from actual climatological records.

III. The Procedure

The basic methodology employed in the ensuing decision-model is that espoused in a book on decision theory by Chernoff and Moses [7]. By combining conditional probabilities, climatological probabilities, and operational loss values for specified actions in the manner to be described below, one can obtain "optimum" operational strategies. Conditional probabilities comprise the "experimental matrix". This matrix contains probabilities that a particular forecast category (F_k) for some meteorological variable will have been forecast, given that a particular observational category (θ_i) occurs. These probabilities are represented in the text by $P(F_k|\theta_i)$. Climatological probabilities, collectively termed the "climatology vector", represent the probabilities of occurrence of the observational categories based on past records. These probabilities are represented in the text by $P(\theta_i)$. The "loss table" contains operational costs incurred for particular actions (A_j) when specified observational categories occur. These values are represented by $L(\theta_i, A_j)$. All of the above values are combined to obtain expected (long-run average) losses by observational category, $L(\theta_i, S_q)$, and, subsequently, the expected loss for each of the possible strategies, $L(S_q)$. The strategy which is operationally feasible and shows the minimum loss is then selected as the optimum strategy. In this case, a strategy is defined as a vector (S_q) composed of the actions taken corresponding to each forecast category. Thus, $S_q = (A_j(F_1), A_j(F_2), \ldots, A_j(F_r))$. S_q is equivalent to "action order" in the attached computer program. For the above variables, the subscript limits are as follows: $i = 1, \ldots, m$; $j = 1, \ldots, n$; $k = 1, \ldots r$; $q = 1, \ldots, t$. A symbolic and conceptual representation of the above decision-model is shown in Figure 1. The actual procedure for computing the $L(S_q)$ is discussed below.

In many instances the use of a computer would be necessary for computing the $L(S_q)$ since many strategies can result from having only a few forecast categories and a few actions. The total number of possible strategies for a given problem is equal to the number of possible actions raised to a power equaling the number of forecast categories. Thus, if there are 4 possible actions and 3 forecast categories, there are 4^3 or 64 strategies that must be simulated. If a computer is used to calculate the losses, large numbers of strategies can be examined.

In their study Chernoff and Moses [7] approach the decision problem in several ways. The technique presented in this technical note is but one of their methods, however, it is felt to be an extremely useful one. Even so, more investigation into the field of decision theory must be accomplished before the best method can be determined for each specific type of problem. Elaboration on the method chosen for this study follows.

A single procedure is followed to determine the expected losses for all strategies in a

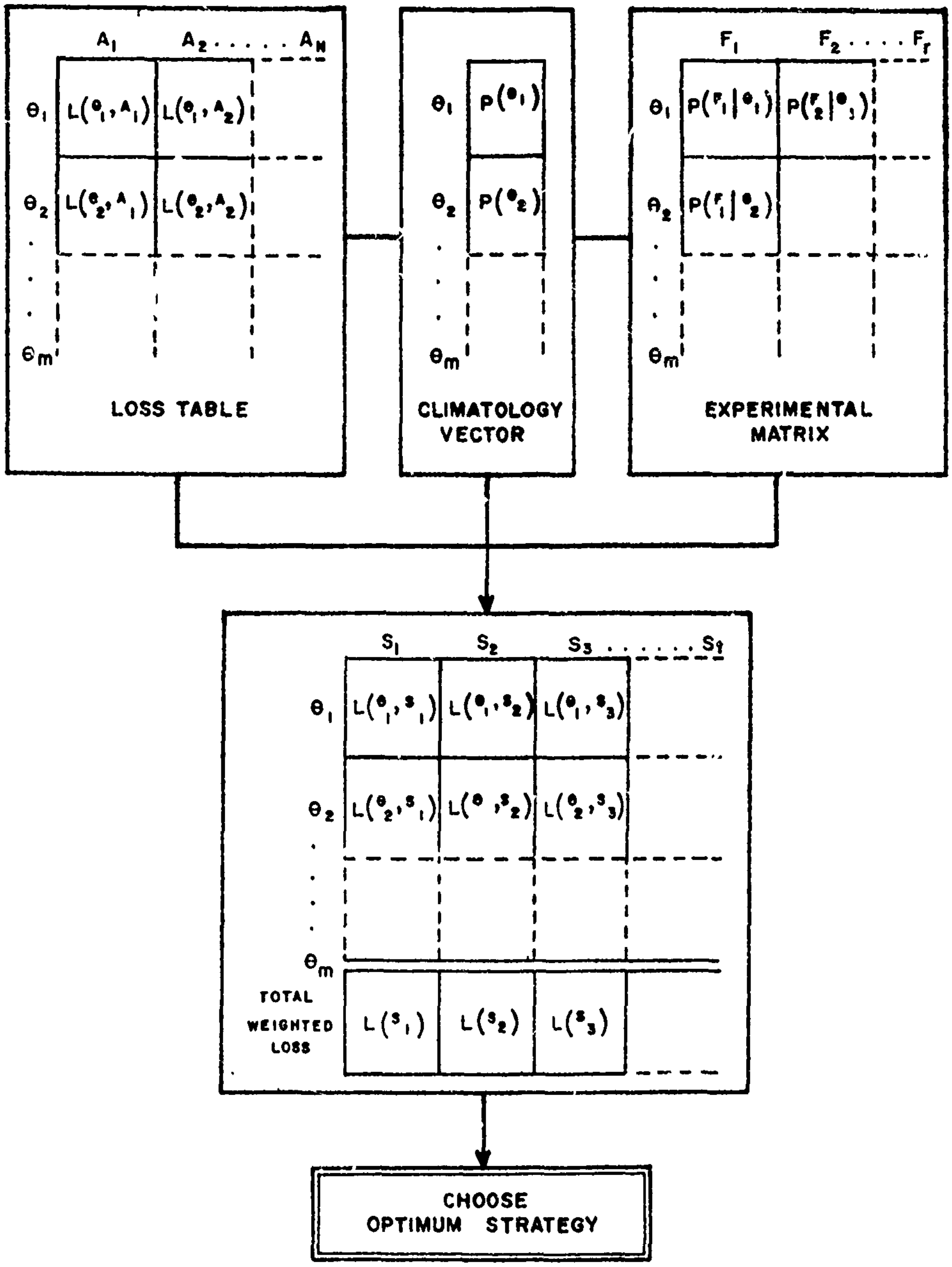

Figure 1

Symbolic and Conceptual Representation

of

Decision Model

given problem. The procedure takes into consideration the cost of taking specified actions under specified observational categories and the probabilities associated with the occurrence of the observational categories and the forecast categories. The first procedural step to compute the expected loss for a given strategy, S_q, is to determine the conditional probability for each action with respect to each observational category, $P(A_j|\theta_i)$. This is done by summing the conditional probabilities for each occurrence of a particular A_j in the strategy vector, S_q. Probabilities of occurrence for each action are thus obtained for each observational category. The second step is to multiply the loss value for each action/observational-category combination by the respective action-probability-of-occurrence value obtained in the first step. The third step is to multiply each result from the second step by the appropriate observational-category-probability-of-occurrence value (climatological probability). The final step is to sum the results of the third step to obtain the expected value of the loss that would result if S_q were implemented. (The above procedure is presented in symbolic fashion in Figure 2.) This procedure is subsequently followed for each S_q, whereupon that strategy which is feasible and has the minimum expected loss is selected as the <u>optimum strategy</u>.

<u>STEP 1</u>: Compute $P_q(A_j|\theta_i)$ for all i's and j's;

where $$P_q(A_j|\theta_i) = \sum_{k=1}^{r} P(F_k|\theta_i) \left[\frac{A_h(F_k)}{A_h(F_k)}\right] J$$

with $\begin{cases} J=1 \text{ if } h = j \\ J=0 \text{ if } h \neq j \end{cases}$

where A_h is that action taken where F_k is given for Strategy Vector S_q.

<u>STEP 2</u>: Compute $L(\theta_i, A_j)\ P_q(A_j|\theta_i)$ for all i's and j's

<u>STEP 3</u>: Compute $L(\theta_i, S_q)$ for all i's and j's;

where $$L(\theta_i, S_q) = P(\theta_i)\ L(\theta_i, A_j)\ P_q(A_j|\theta_i)$$

<u>STEP 4</u>: Compute $L(S_q)$;

where $$L(S_q) = \sum_{i=1}^{m} L(\theta_i, S_q)$$

$$= \sum_{i=1}^{m} \sum_{j=1}^{n} P(\theta_i)\ L(\theta_i, A_j)\ P_q(A_j|\theta_i)$$

Figure 2

Procedure for Computing Expected Loss for Strategy S_q

The above technique is best illustrated in the use of a simple, but somewhat realistic, operational-decision problem. First, a scenario for the problem is presented, followed by a listing of the operational and environmental data used for the problem. A dry-run will then be performed on two of the strategies to illustrate the above procedure. Following this, a description of a computer program which applies the above principles will be presented.

IV. Scenario and Dry-Run.

The scenario will consist of a logistical mission to resupply Base Y. Aircraft are to depart from Base X with the intention of resupplying Base Y. The surface visibility at Base X is considered to be the critical factor in determining whether or not the aircraft should depart for Base Y. Weather at Base Y is assumed to be good in this simplified model (in other words, weather at Base Y is not considered to be a significant factor in the mission completion, e.g., supplies can be paradropped into Base Y). The aircraft may rely on only 06Z and 12Z forecasts of visibility for Base X (made at 00Z and 06Z, respectively). The observation times are also 06Z and 12Z. The forecast and observational categories also include the same visibility intervals($\geq$ 3 miles, $<$ 3 miles). It is risky for the aircraft to take off when the visibility is less than 3 miles. In addition, the planes must depart at either 06Z or 12Z. There are three possible actions that can be taken as a result of a particular forecast. These actions are as follows: A_1 = takeoff -- requires 2 hours preparation time prior to departure; A_2 = cancel mission -- i.e., mission failure; A_3 = delay 6 hours.

Operational losses are distributed as follows: A loss of 1 unit will be incurred for each hour of delay (takes into consideration manhours lost to idle-time, idle planes and equipment, etc.). A loss of 2 units will be incurred for each hour of preparation time required (for fuel, maintenance, man-hours, etc.). A loss of 7 units will occur for each mission completion (due to fuel consumed enroute, wear and tear on equipment, etc.). A loss of 5 units will result from a wrong decision (e.g., action A_1 = takeoff is taken when observational category θ_j = $<$ 3 miles occurs). Finally, a loss of 20 units is incurred for failing to complete the mission (this value may be a quantification of the need for supplies at Base Y).

Figure 3 contains the loss table, climatology vector, and the experimental matrix for the sample problem. For this example, the experimental matrix has been constructed using a persistence forecast (i.e., persistence probability values were used to construct the matrix). The loss table was determined in a somewhat subjective manner by the authors, and assumes that the decision-maker will follow the chosen strategy regardless of the consequences. Remember, the object is to pick that strategy which will result in the lowest long-run average loss. The best strategy may backfire on occasion, but it should do so less often than the other possible strategies. The climatology vector and the experimental matrix are, or have been derived from, real data. The loss table was constructed by summing the possible losses according to the criteria cited in the previous paragraph with respect to the possible combinations of action and observational category. For example, if the observational category is $<$ 3 miles, and the action implemented is a takeoff, considerable cost could be incurred. There will be a loss of 4 units for 2 hours of preparation time. There will also be a 5-unit loss for making a wrong decision, and a 20-unit loss for failing to complete the mission.

	TAKEOFF A_1	CANCEL A_2	DELAY A_3
<3 mi. θ_1	29	20	6
≥3 mi. θ_2	11	25	11

LOSS TABLE

<3 mi. θ_1	.31
≥3 mi. θ_2	.69

CLIMATOLOGY VECTOR

	<3 mi. F_1	≥3 mi F_2
<3 mi. θ_1	.47	.53
≥3 mi. θ_2	.05	.95

EXPERIMENTAL MATRIX

(F_1 and F_2 valid for 06Z but forecast at 00Z; θ_1 and θ_2 valid for 06Z)

Figure 3. Data for Sample Problems

Thus, the total loss for this combination of action and observational category is 29 units.

The set of tables and data shown in Figure 3 is valid for the 00Z decision time (i.e., a decision as to the action to be taken is made as a result of the forecast issued at 00Z. An extension of the model would be to recycle the procedures stated above in conjunction with a new set of data for the 06Z decision time as would be required in the case of a "delay" action from the first cycle. The method of combining costs for the two decision periods, in the case of a delay from the first period,may seem obvious at first glance but further consideration reveals this not to be true. Since it is not clear to the authors how to best combine the two sets of data to obtain viable results, this Note contains an exposition of the procedure and results when dealing with one cycle only.

Given the above data and assumptions, a dry run will now be undertaken for the first and eighth strategies in this example to illustrate the technique more clearly. Since, in this problem, there are three actions and two forecast categories, we have 3^2 or 9 possible strategies. By performing an ordered permutation, it can be seen that $S_1 = (A_1, A_1)$ and $S_8 = (A_3, A_2)$. According to the procedure outlined above, these strategies can be represented as follows:

$$L(S_1) = L(\theta_1, S_1) + L(\theta_2, S_1)$$

$$= P(\theta_1)\,[L(\theta_1, A_1)P_1\,(A_1|\theta_1) + L(\theta_1, A_2)P_1\,(A_2|\theta_1) + L(\theta_1, A_3)P_1\,(A_3|\theta_1)] +$$

$$P(\theta_2)\,[L(\theta_2, A_1)P_1\,(A_1|\theta_2) + L(\theta_2, A_2)P_1\,(A_2|\theta_2) + L(\theta_2, A_3)P_1\,(A_3|\theta_2)]$$

$$L(S_8) = L(\theta_1, S_8) + L(\theta_2, S_8)$$

$$= P(\theta_1)\,[L(\theta_1, A_1)P_8\,(A_1|\theta_1) + L(\theta_1, A_2)P_8\,(A_2|\theta_1) + L(\theta_1, A_3)P_8\,(A_3|\theta_1)] +$$

$$P(\theta_2)\,[L(\theta_2, A_1)P_8\,(A_1|\theta_2) + L(\theta_2, A_2)P_8\,(A_2|\theta_2) + L(\theta_2, A_3)P_8\,(A_3|\theta_2)]$$

Referring to Figure 3 and the above equations, $L(S_1)$ and $L(S_8)$ can be computed as follows:

$L(S_1) = .31 \times [29\times1 + 20\times0 + 6\times0] + .69 \times [11\times1 + 25\times0 + 11\times0] = \underline{16.58\text{ units}}$

$L(S_8) = .31 \times [29\times0 + 20\times.53 + 6\times.47] + .69\times[11\times0 + 25\times.95 + 11\times.05] = \underline{20.93\text{ units}}$

Each of the other strategies is computed in the same manner with the lowest cost, operationally-feasible strategy being selected as the optimum.

V. Computer Program.

As mentioned previously, a computer program has been written which performs the above calculations. The program is written in FORTRAN IV for use by personnel not especially program-oriented. It was designed and programmed on a DEC PDP-10 which was accessed in a time-sharing mode using a Teletype 33 terminal. The program operates in a "conversational" status, in that it allows the user to "converse" with the program as to how the program works, what data are required for input, what options are available, and what type of output is available. A complete listing of the program, including appropriate documentation is contained in Attachment 1. A sample execution run of the program is contained in Attachment 2.

VI. Conclusion.

This program could provide operations or planning personnel with the capability of obtaining pertinent decision-making information in a short period of time, provided the computer capability is readily available. If the program were implemented in conjunction with a cathode ray tube (CRT) display terminal, even faster response and greater effectiveness of the decision-making tool could be realized. The present program is capable of handling up to 3,125 strategies (5^5), but could be easily expanded to include more meteorological variables and more diversified actions; thus, providing the user with greater flexibility. However, the run times and other costs for enhancements of this type are definitely increased and a cost/benefit analysis would have to be performed to determine the feasibility of the more complicated models. For example, a problem that contains 10 possible actions and 6 forecast categories would require that 1,000,000 strategies be simulated, which could run a considerable length of time, depending on the type of computer hardware used.

The concept of combining the operational and meteorological information is the important factor considered in this study. The specific decision-theory approach presented here may or may not be the best way to go. It is, however, a step toward the ultimate goal of minimizing loss of resources over the long-run. There is a definite need for more study in this area of improving operational decision-making through the interaction of environmental and operational factors.

VII. References

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[6] Huschke, R. E.: "Ten Guidelines for the Simulation of Weather-Sensitive Military Operations: Weather and Warplanes II." A report prepared for United States Air Force Project Rand, Rand, Santa Monica, CA, 1971, 29 p.

[7] Chernoff, H. and Moses, L. E.: Elementary Decision Theory, John Wiley & Sons, Inc., New York, 1959, 364 p.

2 Atch
1. Program Listing
2. Sample Run

```
C ****************************** MINLOS ******************************
C
C        THIS PROGRAM WILL COMPUTE LONG-RUN MINIMUM AVERAGE LOSSES FOR
C   SPECIFIC OPERATIONAL STRATEGIES, BASED ON OPERATIONAL LOSS VALUES &
C   WEATHER OCCURRENCE PROBABILITIES.  THE INPUT/OUTPUT DOCUMENTATION IS
C   PRESENTED IN THE PROGRAM EXECUTION PHASE AND IS GEARED EITHER TO THE
C   EXPERIENCED OR NON-EXPERIENCED USER OF THIS PROGRAM, AS APPROPRIATE.
C   LOGIC DOCUMENTATION FOLLOWS.  FOR ASSOCIATED INFORMATION REFER TO
C   FILES IN THE SPECIAL PROJECTS SECTION.
C                                            PETER HALL/JUNE 29,1972
C
C
C ************************** DEFINITIONS **************************
C
C    ACNLOS - TEMPORARY STORAGE FOR THE LOSSES BY ACTION
C    AGAIN  - STORES A 'YES' OR 'NO', FOR RECYCLE OF EXECUTION
C    APRIOR - A PRIORI (CLIMATOLOGICAL) PROBABILITY ARRAY
C    EXPNCE - STORES A 'YES' OR 'NO', TO SEE WHETHER EXPERIENCED
C    EXPTAB - EXPERIMENTAL TABLE ARRAY FOR CONDITIONAL PROBABILITIES
C    I      - DO-LOOP COUNTER AND INDEX
C    IFORMT - ALPHANUMERIC ARRAY FOR STORING VARIABLE FORMATS
C    IOBACN - ARRAY THAT STORES ACTION ORDER FOR EACH STRATEGY
C    J      - DO-LOOP COUNTER AND INDEX
C    KFORMT - ARRAY FOR STORING IFORMT (VARIABLE FORMAT) BEING USED
C    LOSTAB - LOSS TABLE ARRAY
C    MINSRT - STRATEGY NUMBER ARRAY WHEN ASK FOR SORTED OUTPUT
C    N      - DO-LOOP COUNTER AND INDEX, USED IN SORT ROUTINE
C    NACTNS - NUMBER OF ACTIONS IN PROBLEM
C    NBRACN - ACTION NUMBER INDEX
C    NBROUT - NUMBER OF SORTED STRATEGIES TO BE SORTED AND LISTED
C    NN     - DO-LOOP COUNTER AND INDEX, USED IN SORT ROUTINE
C    NO     - DO-LOOP COUNTER AND INDEX FOR NUMBER OF FORECAST
C             CATEGORIES
C    NOBKWD - INDEX THAT REVERSES ORDER OF IOBACN ARRAY
C    NORS   - NUMBER OF FORECAST CATEGORIES IN PROBLEM
C    NS     - DO-LOOP COUNTER AND INDEX FOR NUMBER OF OBSERVATION
C             CATEGORIES
C    NSTATE - NUMBER OF OBSERVATION CATEGORIES IN PROBLEM
C    NSTRAT - NUMBER OF STRATEGIES POSSIBLE IN PROBLEM
C    NWD    - DO-LOOP COUNTER AND INDEX USED TO STORE A FORMAT STATEMENT
C             IN KFORMT
C    SORTED - STORES A 'YES' OR 'NO' FOR SORTING STRATEGIES BY LOSS
C    STALOS - ARRAY FOR CUMULATIVE LOSS IN OBSERVATION CATEGORY
C    STRLOS - ARRAY FOR UNSORTED STRATEGY LOSSES
C    STRSRT - ARRAY FOR SORTED STRATEGY LOSSES
C    YES    - ALPHANUMERIC 'YES' FOR TESTING ANSWERS TO QUESTIONS
C
C
C ************************ PROGRAM LISTING ************************
```

```
C
      REAL LOSTAB
      DIMENSION LOSTAB(5,5),EXPTAB(5,5),IOBACN(5),STALOS(5)
      DIMENSION APRIOR(5),STRLOS(3125),STRSRT(50),MINSPT(50)
      DIMENSION IFORMT(5,4),KFORMT(5)
      DATA IFORMT/5H(22X,,5HI3,12,5HX,2I1,5H,7X,F,5H6.2) ,
     1           5H(22X,,5HI3,12,5HX,3I1,5H,6X,F,5H6.2) ,
     2           5H(22X,,5HI3,11,5HX,4I1,5H,6X,F,5H6.2) ,
     3           5H(22X,,5HI3,11,5HX,5I1,5H,6X,F,5H6.2) /
      DATA YES/3HYES/
C
C ***** REMARKS,EXPLANATION, AND QUESTIONS FOR INPUT.
C
      TYPE 1001
 1001 FORMAT ('0',20X,'****** BAYES STRATEGIES ******'/'0ARE YOU',
     1        ' EXPERIENCED? (YES OR NO)'//)
      ACCEPT 1002, EXPNCE
 1002 FORMAT (A3)
      IF (EXPNCE.EQ.YES) GO TO 50
      TYPE 1000
 1000 FORMAT ('0',5X,'THIS PROGRAM WILL COMPUTE LONG-RUN MINIMUM AVER',
     1 'AGE LOSSES FOR'/' SPECIFIC OPERATIONAL STRATEGIES ("BAYES STR',
     2 'ATEGIES") BASED ON OPERA-'/' TIONAL LOSS VALUES AND WEATHER',
     3 ' OCCURRENCE PROBABILITIES.  THE INPUT'/' PARAMETERS ARE AS',
     4 ' FOLLOWS: (1) THE NUMBER OF ACTIONS AVAILABLE,'/' (2) THE NUM',
     5 'BER OF OBSERVATION CATEGORIES USED, (3) THE NUMBER OF'/' FORE',
     6 'CAST CATEGORIES USED, (4) THE OPERATIONAL COST (LOSS) FOR',
     7 ' EACH'/' COMBINATION OF ACTIONS AND OBSERVATION CATEGORIES,',
     8 ' (5) THE CLIMATOLOG-'/' ICAL PROBABILITY OF OCCURRENCE OF',
     9 ' EACH OBSERVATION CATEGORY, AND'/' (6) THE CONDITIONAL PROBA',
     A 'BILITY FOR EACH COMBINATION OF OBSERVATION'/' AND FORECAST CA',
     1 'TEGORIES (I.E., THE PROBABILITY THAT A PARTICULAR FORE-'/' CA',
     2'ST WAS ISSUED GIVEN THAT A PARTICULAR OBSERVATION CATEGORY'/
     3 ' OCCURRED).'//'      THE INPUT FORMATS ARE AS FOLLOWS: (1), (2',
     4 '), AND (3) SHOULD BE'/' TYPED AS ONE DIGIT INTEGERS; (4), (5)',
     5 ', AND (6) SHOULD BE TYPED AS'/' THREE DIGIT REAL NUMBERS (INC',
     6 'LUDING DECIMAL POINT INSERTED AS'/' APPROPRIATE---0, 1, 2',
     7 ', OR 3 DIGITS TO THE RIGHT OF THE POINT).'/' TYPE CARRIAGE R',
     8 'ETURN AFTER TYPING EACH INPUT VALUE.  THE MAXIMUM'/' NUMBER A',
     9 'LLOWED FOR EACH OF (1), (2), AND (3) IS "5".'/)
      TYPE 1999
 1999 FORMAT('0',5X,'OUTPUT COMMENTS: THE ACTION ORDER IS A SEQUENCE ',
     1'OF NUMBERS TO BE'/' INTERPRETED AS FOLLOWS: THE NUMBER IN THE ',
     2'LEFTMOST POSITION OF THE'/' SEQUENCE REPRESENTS THAT ACTION ',
     3'TO BE TAKEN IF THE FIRST FORECAST'/' CATEGORY IS FORECAST.  ',
     4'THE NUMBER IN THE POSITION IMMEDIATELY TO THE'/' RIGHT OF ',
     5'THE FIRST POSITION IN THE SEQUENCE REPRESENTS THAT ACTION'/
     6' TO BE TAKEN IF THE SECOND FORECAST CATEGORY IS FORECAST; ',
     7'AND SO'/' ON, UNTIL THE NUMBER IN THE RIGHTMOST POSITION OF ',
     8'THE SEQUENCE'/' REPRESENTS THAT ACTION TO BE TAKEN IF THE ',
     9'LAST FORECAST CATEGORY'/' IS FORECAST.  THE ACTION ORDER ',
     1'THUS BECOMES A STRATEGY (I.E., A'/' SET OF DECISION RULES) ',
     2'FOR THE DECISION-MAKER.')
      TYPE 1003
```

```
 1003 FORMAT ('0ROTS OF RUCK!!!'///)
   50 TYPE 1004
 1004 FORMAT ('0NO. OF ACTIONS ='/)
      ACCEPT 1005, NACTNS
 1005 FORMAT (I1)
      TYPE 1010
 1010 FORMAT ('0NO. OF OBS CATEGORIES ='/)
      ACCEPT 1015, NSTATE
 1015 FORMAT (I1)
      TYPE 1020
 1020 FORMAT ('0NO. OF FCST CATEGORIES ='/)
      ACCEPT 1025, NOBS
 1025 FORMAT (I1)
      TYPE 1040
 1040 FORMAT ('0LOSSES (INCLUDE DECIMAL POINT):'/)
      DO 1 I=1,NSTATE
      DO 1 J=1,NACTNS
      TYPE 1044, I,J
 1044 FORMAT ('0(',I1,',',I1,') ='/)
      ACCEPT 1045, LOSTAB(I,J)
 1045 FORMAT (F4.2)
    1 CONTINUE
      TYPE 1030
 1030 FORMAT ('0CLIME PROBABILITIES:'/)
      DO 3 I=1,NSTATE
      TYPE 1034,I
 1034 FORMAT ('0(',I1,') ='/)
      ACCEPT 1035, APRIOR(I)
 1035 FORMAT (F4.2)
    3 CONTINUE
      TYPE 1050
 1050 FORMAT ('0CONDITIONAL PROBABILITIES:'/)
      DO 2 I=1,NSTATE
      DO 2 J=1,NOBS
      TYPE 1054, I,J
 1054 FORMAT ('0(',I1,',',I1,') = '/)
      ACCEPT 1055, EXPTAB(I,J)
 1055 FORMAT (F4.2)
    2 CONTINUE
C
C ***** LOADING REQUIRED FORMAT LINE BASED ON THE NUMBER OF FORECAST
C ***** CATEGORIES.
C
      DO 45 NWD=1,5
      KFORMT(NWD)=IFORMT(NWD,NOBS-1)
   45 CONTINUE
      MN=0
C
C ***** COMPUTING THE NUMBER OF STRATEGIES.
```

```
C
      NSTRAT=NACTNS**NOBS
      NBROUT=NSTRAT
C
C ***** QUESTIONS AND INPUT TO DETERMINE IF SORTED OUTPUT IS DESIRED,
C ***** AND IF SO HOW MANY STRATEGIES ARE TO BE SORTED.
C
      TYPE 1075
 1075 FORMAT ('0DO YOU WANT THE STRATEGIES SORTED BY LOSS, AND LISTED',
     1        ' IN ASCENDING'/'          ORDER? (YES OR NO)'/)
      ACCEPT 1080, SORTED
 1080 FORMAT (A3)
      IF (SORTED.NE.YES) GO TO 44
      TYPE 1085
 1085 FORMAT ('0HOW MANY STRATEGIES WOULD YOU LIKE LISTED?'/
     1        '         (2-DIGIT INTEGER--MAX IS 50)'/)
      ACCEPT 1090, NBROUT
 1090 FORMAT (I2)
C
C ***** COMPUTING STRATEGY LOSS VALUES USING BAYESIAN APPROACH.
C ***** FOR DETAILED EXPLANATION OF THE BAYESIAN METHOD REFER TO
C ***** "ELEMENTARY DECISION THEORY" BY CHERNOFF AND MOSES (CHAPTERS 1
C ***** AND 6); PUBLISHED BY WILEY, COPYRIGHT 1959.
C
   44 DO 10 NBR=1,NSTRAT
      CALL ACNORD (NBR,NOBS,NACTNS,IOBACN)
      DO 20 NS=1,NSTATE
      DO 30 NO=1,NOBS
      NOBKWD=NOBS-NO+1
      NBRACN=IOBACN(NOBKWD)
      ACNLOS=EXFTAB(NS,NO)*LOSTAB(NS,NBRACN)
      STALOS(NS)=STALOS(NS)+ACNLOS
   30 CONTINUE
      STALOS(NS)=STALOS(NS)*APRIOR(NS)
      STRLOS(NBR)=STRLOS(NBR)+STALOS(NS)
   20 CONTINUE
      IF (SORTED.NE.YES) GO TO 21
C
C ***** BEGINNING OF "PUSHDOWN" SORT FOR SORTED OUTPUT.
C
      DO 23 N=1,NBROUT
      IF (STRLOS(NBR).LE.STRSRT(N)) GO TO 26
      IF (STRSRT(N).NE.0.) GO TO 23
      STRSRT(N)=STRLOS(NBR)
      MINSRT(N)=NBR
      GO TO 21
   23 CONTINUE
      GO TO 21
   26 DO 27 NN=NBROUT,N+1,-1
      STRSRT(NN)=STRSRT(NN-1)
      MINSRT(NN)=MINSRT(NN-1)
   27 CONTINUE
      STRSRT(N)=STRLOS(NBR)
      MINSRT(N)=NBR
```

```
C
C ***** RESETTING LOSSES,BY OBSERVATION CATEGORY,TO ZERO.
C
   21 DO 25 NS=1,NSTATE
      STALOS(NS)=0.
   25 CONTINUE
   10 CONTINUE
C
C ***** TYPING OUTPUT HEADINGS.
C
      TYPE 1060
 1060 FORMAT('0',27X,'BAYES STRATEGIES'//20X,'STRATEGY',7X,'ACTION',7X,
     1          'LOSS'/21X,'NUMBER',8X,'ORDER'//)
      IF (SORTED.EQ.YES) GO TO 90
C
C ***** NON-SORTED OUTPUT ROUTINE
C
      DO 40 I=1,NSTRAT
      NBR=I
      CALL ACNORD (NBR,NOBS,NACTNS,IOBACN)
      TYPE KFORMT, NBR,(IOBACN(NOBKWD),NOBKWD=NOBS,1,-1),STRLOS(I)
   40 CONTINUE
      GO TO 95
C
C ***** SORTED OUTPUT ROUTINE
C
   90 DO 41 I=1,NSROUT
      NBR=MINSRT(I)
      CALL ACNORD (NBR,NOBS,NACTNS,IOBACN)
      TYPE KFORMT, NBR, (IOBACN(NOBKWD),NOBKWD=NOBS,1,-1),STRSRT(I)
   41 CONTINUE
C
C ***** QUESTIONING AS TO WHETHER USER WOULD LIKE ANOTHER TRY AT IT.
C
   95 TYPE 1065
 1065 FORMAT ('0WOULD YOU LIKE TO TRY AGAIN? (YES OR NO)'/)
      ACCEPT 1070, AGAIN
 1070 FORMAT (A3)
      IF (AGAIN.NE.YES) STOP
C
C ***** ZEROING OUT ARRAYS FOR ANOTHER TRY.
C
      DO 64 I=1,NOBS
      IOBACN(I)=0
   64 CONTINUE
      DO 65 I=1,NSTATE
      STALOS(I)=0.
      APRIOR(I)=0.
      DO 65 J=1,NOBS
      LOSTAB(I,J)=0.
      EXPTAB(I,J)=0.
```

```
   66 CONTINUE
      DO 67 I=1,NSTRAT
      STRLOS(I)=0.
   67 CONTINUE
      IF (SORTFD.NE.YES) GO TO 68
      DO 68 I=1,NBROUT
      STRSRT(I)=0.
      MINSRT(I)=0
   68 CONTINUE
      GO TO 50
      END
C
C ****************************** ACNORD ******************************
C
C        THIS SUBROUTINE COMPUTES THE ACTION ORDER FOR EACH STRATEGY
C  NUMBER AS REQUIRED.  PARAMETERS (IN ORDER) ARE: STRATEGY NUMBER,
C  NUMBER OF FORECAST CATEGORIES, NUMBER OF ACTIONS FOR INPUT, AND
C  ACTION ORDER ARRAY FOR OUTPUT.
C
C
C ***************************** DEFINITONS ****************************
C
C   DVIDND  - DIVIDEND
C   IORACN  - ACTION ORDER ARRAY
C   IQUOT   - QUOTIENT
C   J       - DO-LOOP COUNTER AND INDEX
C   NACTNS  - NUMBER OF ACTIONS
C   NBR     - STRATEGY NUMBER
C   NOBS    - NUMBER OF FORECAST CATEGORIES
C
C
C ****************************PROGRAM LISTING *************************
C
      SUBROUTINE ACNORD (NBR,NOBS,NACTNS,IORACN)
      INTEGER DVIDND
      DIMENSION IORACN(NOBS)
      IQUOT=NBR-1
      DO 10 J=1,NOBS
      DVIDND=IQUOT
      IF (IQUOT.EQ.0) GO TO 9
      IQUOT=DVIDND/NACTNS
    9 IORACN(J)=DVIDND-NACTNS*IQUOT+1
   10 CONTINUE
      RETURN
      END
C
C *********************************************************************
```

ARE YOU EXPERIENCED? (YES OR NO)

NO

THIS PROGRAM WILL COMPUTE LONG-RUN MINIMUM AVERAGE LOSSES FOR SPECIFIC OPERATIONAL STRATEGIES ("BAYES STRATEGIES") BASED ON OPERATIONAL LOSS VALUES AND WEATHER OCCURRENCE PROBABILITIES. THE INPUT PARAMETERS ARE AS FOLLOWS: (1) THE NUMBER OF ACTIONS AVAILABLE, (2) THE NUMBER OF OBSERVATION CATEGORIES USED, (3) THE NUMBER OF FORECAST CATEGORIES USED, (4) THE OPERATIONAL COST (LOSS) FOR EACH COMBINATION OF ACTIONS AND OBSERVATION CATEGORIES, (5) THE CLIMATOLOGICAL PROBABILITY OF OCCURRENCE OF EACH OBSERVATION CATEGORY, AND (6) THE CONDITIONAL PROBABILITY FOR EACH COMBINATION OF OBSERVATION AND FORECAST CATEGORIES (I.E., THE PROBABILITY THAT A PARTICULAR FORECAST WAS ISSUED GIVEN THAT A PARTICULAR OBSERVATION CATEGORY OCCURRED).

THE INPUT FORMATS ARE AS FOLLOWS: (1), (2), AND (3) SHOULD BE TYPED AS ONE DIGIT INTEGERS; (4), (5), AND (6) SHOULD BE TYPED AS THREE DIGIT REAL NUMBERS (INCLUDING DECIMAL POINT INSERTED AS APPROPRIATE---0, 1, 2, OR 3 DIGITS TO THE RIGHT OF THE POINT). TYPE CARRIAGE RETURN AFTER TYPING EACH INPUT VALUE. THE MAXIMUM NUMBER ALLOWED FOR EACH OF (1), (2), AND (3) IS "5".

OUTPUT COMMENTS: THE ACTION ORDER IS A SEQUENCE OF NUMBERS TO BE INTERPRETED AS FOLLOWS: THE NUMBER IN THE LEFTMOST POSITION OF THE SEQUENCE REPRESENTS THAT ACTION TO BE TAKEN IF THE FIRST FORECAST CATEGORY IS FORECAST. THE NUMBER IN THE POSITION IMMEDIATELY TO THE RIGHT OF THE FIRST POSITION IN THE SEQUENCE REPRESENTS THAT ACTION TO BE TAKEN IF THE SECOND FORECAST CATEGORY IS FORECAST; AND SO ON, UNTIL THE NUMBER IN THE RIGHTMOST POSITION OF THE SEQUENCE REPRESENTS THAT ACTION TO BE TAKEN IF THE LAST FORECAST CATEGORY IS FORECAST. THE ACTION ORDER THUS BECOMES A STRATEGY (I.E., A SET OF DECISION RULES) FOR THE DECISION-MAKER.

ROTS OF RUCK!!!

NO. OF ACTIONS =
3

NO. OF OBS CATEGORIES =
2

NO. OF FCST CATEGORIES =
2

LOSSES (INCLUDE DECIMAL POINT):

(1,1) =
29.

(1,2) =
20.

(1,3) =
6.

(2,1) =
11.

(2,2) =
25.

(2,3) =
11.

CLIME PROBABILITIES:

(1) =
.31

(2) =
.69

CONDITIONAL PROBABILITIES:

(1,1) =
.47

(1,2) =
.53

(2,1) =
.05

(2,2) =
.95

```
DO YOU WANT THE STRATEGIES SORTED BY LOSS, AND LISTED IN ASCENDING
    ORDER? (YES OR NO)
NO
```

BAYES STRATEGIES

STRATEGY NUMBER	ACTION ORDER	LOSS
1	11	16.59
2	12	24.28
3	13	12.80
4	21	1[illegible].75
5	22	23.45
6	23	11.97
7	31	13.23
8	32	20.93
9	33	9.45

```
WOULD YOU LIKE TO TRY AGAIN? (YES OR NO)
YES

NO. OF ACTIONS =
3

NO. OF OBS CATEGORIES =
2

NO. OF FCST CATEGORIES =
2

LOSSES (INCLUDE DECIMAL POINT):

(1,1) =
25.

(1,2) =
20.

(1,3) =
6.

(2,1) =
11.
```

(2,2) =
25.

(2,3) =
11.

CLIME PROBABILITIES:

(1) =
.31

(2) =
.69

CONDITIONAL PROBABILITIES:

(1,1) =
.47

(1,2) =
.53

(2,1) =
.05

(2,2) =
.95

DO YOU WANT THE STRATEGIES SORTED BY LOSS, AND LISTED IN ASCENDING
ORDER? (YES OR NO)
YES

HOW MANY STRATEGIES WOULD YOU LIKE LISTED?
(2-DIGIT INTEGER--MAX IS 50)
9

BAYES STRATEGIES

STRATEGY NUMBER	ACTION ORDER	LOSS
9	33	9.45
6	23	11.97
3	13	12.80
7	31	13.23
4	21	15.75
1	11	16.58
8	32	20.53
5	22	23.45
2	12	24.29

WOULD YOU LIKE TO TRY AGAIN? (YES OR NO)
NO

CPU TIME: 7.96 ELAPSED TIME: 5:33.00
NO EXECUTION ERRORS DETECTED

EXIT.
↑C

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13. ABSTRACT

The model discussed in this Note combines conditional climatological probabilities, climatological probabilities, and operational loss values for specified actions in a manner to make the best operational decision. A sample scenario is given and demonstrated using a hypothetical problem of airlift supply.

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LIST OF USAFETAC TECHNICAL NOTES

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71-2	A Reprint of Use of FOUS (Detailed PE Guidance) (AWS distribution only) (AD-719866)	Mar 71
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